PERSPECTIVES: PALEOCLIMATE

# A Slow Dance for El Niño

Julia Cole

In many parts of the world, climate responds to the interannual beat of the El Niño–Southern Oscillation (ENSO) in the tropical Pacific. The past 20 years have witnessed the two strongest (and costliest) El Niño events in the historical record, leading many to speculate that ENSO may be changing as a result of global warming. This speculation is contentious, not least because models show that a wide range of ENSO behavior may occur without considering influences from outside the equatorial Pacific. In this issue on page 1511, Tudhope *et al.* (*1*) use the paleoclimatic record preserved in New Guinea corals to argue that ENSO has responded to external forcings associated with glacial-interglacial cycles of the past 130,000 years. Their results provide strong support for the idea that ENSO may be more responsive to global change than previously thought.

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Tudhope *et al.*'s study expands on previous work in many important ways. First, at their New Guinea site, ENSO produces a clear and direct climate signal both in instrumental data and in modern coral records. This lends confidence to their interpretation of the paleoclimatic records in terms of ENSO variability. In contrast, paleoclimate ENSO records from outside the tropical Pacific rely on the assumption that the remote impacts of ENSO were the same in the past as they are today—a dubious assumption because teleconnections can depend on background climate, which changes (*2*, *3*). Second, the new coral records have near monthly resolution and reveal the full range of interannual ups and downs associated with ENSO, including the intensity of individual events. Third, the study site is probably unique because rapid tectonic uplift has revealed spectacular exposures of corals that date to glacial times, when sea level was up to 120 m lower. Finally, their suite of well-dated records from a single site allows them to consider how changes in mean climate and forcings have produced the changes in ENSO intensity.

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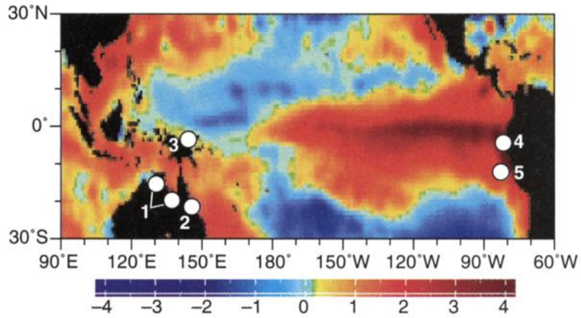


**Location of paleoclimate study sites for mid-Holocene ENSO conditions.** Numbered sites in the map are described in the table below. The map displays sea surface temperatures for February 1998, representing strong El Niño conditions. It is available at http://ingrid.ldeo.columbia.edu/SOURCES/.IGOSS/.nmc. [Adapted from (*16*).]

Other studies have attempted to decipher the history of ENSO in the geological record. Particular attention has been focused on the mid-Holocene interval (~5000 to 6000 years before present), when the seasonal distribution of the solar radiation received at Earth's surface (insolation) was different, but mean climate was comparable to today. Records from the margins of the tropical Pacific (see the figure) each present a slightly different view of mid-Holocene ENSO variability (see the table) because they use different climate proxies and the ENSO signal is site specific.

Model results and paleoclimatic observations are beginning to yield a consistent picture for the mid-Holocene. Model studies show reduced mean sea surface temperatures in the eastern and central equatorial Pacific (*3*, *4*) compared with today. A cooler eastern and central Pacific would explain the fewer large El Niño events expressed in an Ecuador lake record (*5*). Modeled ENSO variability is comparable to modern variability (*3*) or somewhat attenuated, with weaker El Niños and slightly enhanced La Niñas (*4*). Regional warming suggested by data from the westernmost Pacific (*4*, *6*) supports this picture of a more La Niña–like average state. Reduced interannual variability in northern Australia (*6*–*8*) and New Guinea (*1*) suggests a weaker ENSO overall and with weakened teleconnections. The presence of warm water mollusks of mid-Holocene age on the now-cool Peru coast (*9*) is at variance with these inferences, but coastal geomorphology (*10*) or regional oceanic influences (*4*) may explain these observations. The moderate disagreement among modeled amplitudes of mid-Holocene ENSO (*3*, *4*) reminds us that no model simulates even the modern ENSO flawlessly.

These mid-Holocene results, as well as more recent data from corals elsewhere in the Pacific (*11*, *12*), suggest that ENSO is influenced by relatively subtle background

**PACIFIC PALEOCLIMATE STUDIES THAT BEAR ON MID-HOLOCENE ENSO VARIABILITY**

| Site | Proxy evidence | Paleoclimate observations | Conclusions regarding mid-Holocene ENSO |
|---|---|---|---|
| (1) McGlone *et al.* (*8*); Shulmeister and Lees (*7*) | Pollen in north Australian lake sediments spanning the Holocene | Modern drought-adapted taxa not present before ~5000 years ago | ENSO variability much weakened or absent |
| (2) Gagan *et al.* (*6*) | 25 years of coral Sr/Ca and $\delta^{18}O$ data from a Great Barrier Reef coral ~5400 years before present (B.P.) | Interannual hydrologic variability nearly absent compared with modern; background conditions warm | ENSO variability absent |
| (3) Tudhope *et al.* (*1*) | 49 years of coral $\delta^{18}O$ from northern New Guinea dated at ~6500 years B.P. | Interannual variability substantially damped compared with modern | ENSO variability weak |
| (4) Rodbell *et al.* (*5*) | Landslide deposits in an Ecuador lake resulting from heavy rains (0 to 12,000 years B.P.) | Flood deposits occurred less frequently before ~5000 years ago | Strong El Niño events more rare |
| (5) Sandweiss *et al.* (*9*) | Presence of invertebrate fauna that prefer specific thermal regimes on Peru coast | Warm-loving assemblages present from 5000 to 8000 years B.P. north of 10°S | Warm tropical water present consistently; ENSO variability absent and mean is El Niño–like |

climate changes. The glacial-interglacial fluctuations explored by Tudhope *et al.* document ENSO's sensitivity to more severe climate change. At their site, modern (late 19th century to today) corals show the highest amplitude of interannual ENSO variance of all samples over the past 130,000 years—even in the late 19th century when anthropogenic greenhouse forcing was minimal.

The coral records preserve a mixed signal of rainfall and ocean temperatures, and changes in interannual variability may relate to either or both of these. Tudhope *et al.* use multidecadal sequences (18 to 235 years) obtained from several well-dated intervals over the past 130,000 years to argue that in the past, ENSO intensity has been damped relative to modern by two factors. First, the 22,000-year precessional cycle of Earth's orbit changes the seasonal insolation and alters the strength of Pacific trade winds during seasons that are critical for the growth of interannual anomalies. Second, a suppression of ENSO fluctuations during glacial intervals is implied by the glacial-age samples in their record.

The first mechanism for damping ENSO has been studied in climate models of varying complexity. In a simple model of the equatorial Pacific Ocean and atmosphere, the seasonal insolation changes associated with the precession of Earth's equinoxes alter the seasonal strength of the trade winds. When perihelion (the point in Earth's orbit where Earth is closest to the sun) falls in the boreal summer or autumn, the trade winds in that season are strengthened, inhibiting the development of warm El Niño anomalies (*13*). Moreover, the Asian monsoon intensifies when perihelion falls in the boreal summer, and this well-known response has been shown to enhance Pacific summertime trade winds in a global coupled ocean-atmosphere model (*4*). These seasonally forced responses should act together to weaken ENSO variability in the mid-to-late Holocene and to enhance it when perihelion falls in boreal winter, as it does today.

The mechanisms for glacial ENSO weakening are not nearly as well understood. Tudhope *et al.* suggest several possibilities, including weaker ocean-atmosphere interactions in a cooler Pacific and intensified trade winds resulting from a stronger average temperature gradient across the Pacific. A lower sea level that exposes shallow continental shelves in the western Pacific may also anchor the Indonesian Low atmospheric convection system, whose mobility during ENSO is critical for propagating ENSO's impacts to the extratropics.

However, one can also imagine mechanisms that may strengthen ENSO in a glacial world. For example, a shallower, steeper thermocline in the eastern Pacific could lead to greater interannual variability. In initial results from the National Center for Atmospheric Research (NCAR) coupled climate model, more intense ENSO variability is simulated during the Last Glacial Maximum, although precise mechanisms have not yet been identified (*14*). The inference of weaker glacial ENSO from the coral data does not necessarily conflict with this simulation, however. The "glacial" intervals in the Tudhope study [at 40,000, 85,000, 112,000, and 130,000 years before present (*15*)] are less extreme than the Last Glacial Maximum (LGM), and their precessional forcings are not uniformly the same as those at the LGM. Competing mechanisms could push the ENSO system in either direction during glacial times; additional data are required to determine which ones win out when.

Records such as those preserved in Tudhope *et al.*'s New Guinea corals are rare and offer only tantalizingly brief glimpses of past variability. Short records risk misrepresenting the full range of interannual variability. Nonetheless, Tudhope *et al.* identify a pattern in the amplitude of ENSO that is consistent with a response to changing seasonal insolation and background climate state. Their hypothesis essentially predicts the amplitude of ENSO variance as these boundary conditions change—a proposition clearly testable with additional samples. As more information about ENSO's slow dance to orbital rhythms is uncovered, we will better understand its sensitivity to ongoing climate change and its potential role as a feedback or amplifier in the global climate system.


**References and Notes**

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# Was the Medieval Warm Period Global?

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The reconstruction of global temperatures during the last millennium can provide important clues for how climate may change in the future. A recent, widely cited reconstruction (*1*) leaves the impression that the 20th century warming was unique during the last millennium. It shows no hint of the Medieval Warm Period (from around 800 to 1200 A.D.) during which the Vikings colonized Greenland (*2*), suggesting that this warm event was regional rather than global. It also remains unclear why just at the dawn of the Industrial Revolution and before the emission of substantial amounts of anthropogenic greenhouse gases, Earth's temperature began to rise steeply.

Was it a coincidence? I do not think so. Rather, I suspect that the post-1860 natural warming was the most recent in a series of similar warmings spaced at roughly 1500-year intervals throughout the present interglacial, the Holocene. Bond *et al.* have argued, on the basis of the ratio of iron-stained to clean grains in ice-rafted debris in North Atlantic sediments, that climatic conditions have oscillated steadily over the past 100,000 years (*3*), with an average period close to 1500 years. They also find evidence for the Little Ice Age (from about 1350 to 1860) (*3*). I agree with the authors that the swing from the Medieval Warm Period to the Little Ice Age was the penultimate of these oscillations and will try to make the case that the Medieval Warm Period was global rather than regional.

One difficulty encountered when trying to reconstruct Holocene temperature fluctuations is that they were probably less than 1°C. In my estimation, at least for time scales greater than a century or two, only

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